Accretion Discs Boundary Layers in classical TTauri

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ABSTRACT

Results of one-dimensional time dependent calculations of geometrically thin accretion discs boundary layers are presented for classical TTauri stars, for various values of M_* (0.8, $1.0 M_\odot$), R_* (1 .6, '2.15, $4.3 R_\odot$) and $\dot{M}$ (5 x 10-9 – 5 x $10^{-7} M_\odot/y$). The results exhibit a thermal boundary layer ($\delta_{BL}^{Th} \approx 0.1 - 0.2 R_*$) much larger than the dynamical one($\delta_{BL}^{dyn} \approx$ few percent), with characteristic low temperatures ($T_{BL}^{eff} \approx$ 5- 6 x $10^3 K$). *In* the regime of a very low mass accretion rate characteristic of TTauri systems, the mid-plane temperature in the disc drops well below 104 K (a few $\approx 10^3 K$ at most), a very sharp transition region separates the hot ionized thermal boundary layer region and the cool neutral disc. For low value of the alpha viscosity prescription ($\alpha \approx$ 0.01) the medium is optically thin in the cool disc, and slightly optically thick in the hot thermal boundary layer region. For higher values of alpha ($\alpha \approx$ *0.1)* the optical depth in the boundary layer region decr cases ($\tau \approx 1$) and its temperature increases slightly, while the disc becomes partially ionized and optically thicker (τ > 1).

Subject headings: Accretion, Accretion Discs - Stars: Formation - Stars: Pre-Main-Sequence

1. Introduction

Some observable systems, which have been associated with a central star accreting matter from a disc, are the T Tauri stars. The T Tauri are pre-main sequence stars accreting matter from a disc, remanent of the protostellar cloud. Observations show that the velocity field of the circumstellar gas exhibits a doubled-peak spectrum characteristic of a rotating disc (Koerner, Sargent & Beckwith 1993; Koerner & Sargent 1995). In addition, the spectra of T Tauri stars exhibit strong ultraviolet and infrared excess (when compared to main sequence stars of similar spectral type) which can be matched with a standard thin disc and boundary layer model surrounding the central star (Bertout, Basri & Bouvier 1988; Hartigan et al. 1989; Basri & Bertout 1989; Hartigan et al. 1991; Bertout et al, 1993). The spectra of T Tauri systems was fitted first with simple estimates of optically thick boundary layers widths and temperatures (Bertout et al. 1988; Hartigan et al. 1989). Later on, estimates of optically thin boundary layer ($\tau \approx 1$) were constructed to account for the Balmer jump observed in the spectra of many T Tauri systems (Basri & Bertout 1989; Hartigan et al. 1991). With mass accretion rates of $\dot{M} \approx 1 - 100 \times 10^{-9} M_{\odot}/y$, T Tauri stars are believed to be accreting young stellar systems in quiescence. The perturbation of such low mass accretion discs around a T Tauri star is proned to produce the FU Orionis behaviour - outburst state of the accreting young stellar object with $\dot{M} \approx 1 - 30 \times 10^{-5} M_{\odot}/y$ (Clarke, Lin & Papaloizou 1989; Clarke, Lin & Pringle 1990; Bell & Lin 1994; Bell et al. 1995). The Fu Orionis behaviour (Kenyon, Hartmann & Hewett 1988) appears whenever the perturbation is able to trigger the thermal ionization instability, when the disc mid-plane is partially ionized at some intermediate radius (Lin & Papaloizou 1985).

Recently, numerical models have been able to reproduce both the dynamics and the thermal structure of the boundary layer. One-dimensional steady-state calculations of boundary layers were carried out for pre-main stars (Bertout & Regev 1992; Popham et al. 1993; Lioure & Le Contel 1994; Regev & Bertout 1995). The opacity gap in the low temperature regime and the ionization processes were not taken into account in these models, making them, therefore, inadequate to treat the sharp transition between the cool neutral disc and the hot ionized boundary layer in the low mass accretion discs around T Tauri stars.

More recently, a one-dimensional time dependent spectral code was used to model accretion discs boundary layers in various systems (Godon 1995a; Godon, Regev & Shaviv 1995; Godon 1995b; Godon 1995c). Models of pre-main sequence stars were computed with an accreting star of mass $M_* = 1 \times M_{\odot}$, radius $R_* = 4.3 \times R_{\odot}$, and mass accretion rates of $\dot{M} = 5 \times 10^{-7} - 1 \times 10^{-4} M_{\odot}/y$ (Godon 1995b, paper 1). These first calculations were able to reproduce the temperature and width of boundary layers as expected from simple fits of the observations of TTauri and FU Orionis stars (Bertout et al. 1988; Hartigan et al. 1989). It is the purpose of the present work to model the classical TTauri star accretion disc boundary layer with low mass accretion rates ($\dot{M} = 1. - 100 \times 10^{-9} M_\odot/y$) and small optical depth ($\tau \approx 1$ in the boundary layer). The spectral code used in paper I has been presently improved to treat more efficiently the partially ionized region and the transition between optically thick and optically thin media. Moreover, the numerical code has been implemented with the use of a fourth order Runge-Kutta method, and a Modified Chebyshev Pseudospectral Method (Kosloff & Tal-Ezer 1993).

The equations, assumptions, and the numerical method are described in section 2. The results are presented and discussed in section 3.

2. Boundary Layer Modeling

In this section we give an overview of the numerical and physical assumptions made to model accretion disc boundary layers. More details can be found in Paper I as well as in Godon et al. (1995).

2.1. The governing equations

The equations are written in cylindrical coordinates (r, ϕ, z), under the assumption of axi-symmetry $\partial/\partial\phi = 0$, and they are integrated in the vertical direction. The disc is further assumed to be geometrically thin and in hydrostatical equilibrium in the vertical direction. This standard assumptions lead to the vertical thickness of the disc $H = c_s/\Omega_K$.

All the equations are time-dependent, they include the gravity of the accreting star, viscosity, and radiative transfer (in both the vertical and radial direction). The equations have the following form:
the conservation of mass

$$\frac{\partial \rho}{\partial t} = -\frac{1}{r}\frac{\partial}{\partial r}(r\rho v_r), \qquad (1)$$

the conservation of radial momentum

$$\frac{\partial}{\partial t}(\rho v_r) = -\frac{1}{r}\frac{\partial}{\partial r}\left[r(\rho v_r^2 - R_{rr})\right] + r\rho\Omega^2 - \frac{R_{\phi\phi}}{r} - \rho\frac{GM}{r^2} - \frac{\partial P}{\partial r}, \qquad (2)$$

the conservation of angular momentum

$$\frac{\partial}{\partial t}(r\rho\Omega) = -\frac{1}{r}\frac{\partial}{\partial r}\left[r(r\rho v_r\Omega - R_{r\phi})\right] - \rho v_r\Omega + \frac{R_{r\phi}}{r}, \qquad (3)$$

and the conservation of energy

$$\frac{\partial}{\partial t}(\rho\epsilon) = -\frac{1}{r}\frac{\partial}{\partial r}(r\rho v_r \epsilon) - \frac{P}{r}\frac{\partial}{\partial r}(r v_r) + \Phi - \Lambda, \tag{4}$$

where v_r is the radial velocity, Ω is the angular velocity, G is the gravity constant, M is the mass of the star, T is the mid-plane temperature, ρ is the density and P is the pressure. The energy is given by

$$\rho\epsilon = \frac{3}{2}\frac{\mathcal{R}}{\mu}\rho T + \chi_H H^+ + \frac{4\pi u}{c},$$

where $\mathcal{R}$ is the gas constant, μ the mean molecular weight, χ_H is the ionization potential of the Hydrogen, H^+ is the number of Hydrogen ions per unit volume, c is the speed of light, and u is the energy due to radiation (see section 2.2.1 equation 8). The Reynolds stress tensor is defined as $R_{ij} = 2\nu\rho D_{ij}$, ν is the coefficient of the viscosity (see section 2.2.4) and D_{ij} is the deformation tensor. The dissipation] function is given by

$$\Phi = 2\nu\rho(D_{rr}^2 + D_{\phi\phi}^2 + D_{zz}^2 + 2D_{r\phi}^2 + 2D_{z\phi}^2 + 2D_{rz}^2), \tag{5}$$

and the elements of the deformation tensor are $D_{rr} = \partial v_r/\partial r$, $D_{\phi\phi} = v_r/r$, $D_{r\phi} = \frac{1}{2}r(\partial\Omega/\partial r)$, $D_{zz} = D_{rz} = D_{z\phi} = 0$.

The leak of energy due to radiation is obtained through the relation

$$\Lambda = div(\mathcal{F}) = \frac{1}{r}\frac{\partial}{\partial r}(rF_r) + \frac{F_z}{H},$$

where the fluxes of energy F_r and F_z are given in section 2.2.1.

2.2. The physical assumptions

in the present work, some of the physical assumptions (made in paper 1) have been improved. The energy now includes a term for the ionization potential of the Hydrogen. Furthermore, the treatment of radiation, in the transition region between optically thick and optically thin, has been improved.

2.2.1. The radiative process

In the limit of an optically thick medium the vertical flux of energy can be written

$$F_z = \frac{4acT^3}{3\kappa\rho}\frac{\partial T}{\partial z} \approx \frac{4acT^4}{3\tau},$$

where $\tau = \kappa \rho H$ is the optical depth, κ is the opacity, and we have substituted $\partial T/\partial z \approx T/H$. In the limit of an optically thin medium one expects the flux to be given by

$$F_z \approx \frac{4ac}{3} \tau_a T^4,$$

where TO is the absorptive optical depth $\tau_a = \kappa_a \rho H$, and κ_a is the absorptive opacity. A convenient approximation which treats smoothly the transition between optically thick and optically thin is given by Hubeny (1990)

$$F_z = \frac{2ac}{3} \frac{T^4}{\tau + 2/\sqrt{3} + 2/3\tau_a}.$$

For the radial flux we define $\tau_r = \kappa \rho H_r$ - the optical depth in the radial direction, $\tau_{ra} = \kappa_a \rho H_r$ - the absorptive optical depth, and $H_r = T(\partial T/\partial r)^{-1}$ - the temperature scale height in the radial direction. The fluxes of energy are then written

$$F_z = \frac{2ac}{3} \frac{T^4}{\tau + 2/\sqrt{3} + 2/3\tau_a}, \tag{6}$$

$$F_r = \frac{4ac}{3} \frac{T^4}{\tau_r + 1/\sqrt{3} + 4/3\tau_{ra}}. \tag{7}$$

The mean intensity of the energy radiation is obtained through the approximation

$$\frac{F_r}{H_r} + \frac{F_z}{H} = 4\pi \kappa_a \rho (B - u), \tag{8}$$

where $B = acT^4/4\pi$ is the value of u corresponding to black body radiation. In the optically thick regime $u \to B = acT^4/4\pi$, while in the optically thin regime $u \to 0$.

2.2.2. *The equations of state*

In all the models presented here, the temperature and the density vary by several orders of magnitude. At very low temperatures ($T < 10^4 K$) the hydrogen gas is neutral, while at higher temperatures the gas becomes ionized and radiation pressure might be important.

The Saha equation is used to determined the degree of ionization. The effect of the partial ionization on the pressure and energy are of the Order of ≈ 1. The partial ionization affects mainly the opacity by the presence the "gap" a jump of several orders of magnitude in the opacity (see section 2.2.5).

The equation of state is given by:

$$P = \frac{\mathcal{R}}{\mu}\rho T + \frac{4\pi u}{3c} ,$$

where u is given in equation (8).

2.2.3. initial and *boundary* conditions

We place the inner boundary of the computational domain at the stellar surface ($r = R_*$) and allow matter to flow into the star at a constant rate (M). We furthermore consider a non flux boundary condition $dT/dr = 0$ at the inner boundary. At the outer boundary of the computational domain ($r = 2R_*$) we impose a standard Keplerian thin disc. The matter enters though the outer boundary at the same rate as it flows through the inner boundary into the stellar surface (M).

The initial conditions are the superposition of an isothermal atmosphere and an inflowing thin Keplerian disc.

2.2.4. *Viscosity prescription*

In the calculations, we use a viscosity of the form:

$$\nu = \alpha c_s \tilde{H}, \tag{9}$$

where $c_s^2 \approx P/\rho$ is the sound speed, $\tilde{H} = (H^{-2} + H_{pr}^{-2})^{-1/2}$ and H_{pr} is the pressure scale height in the radial direction $H_{pr} = P(\partial P/\partial r)^{-1}$. For high radial infall Velocities, the scale height $\tilde{H}$ can be written (Paper 1):

$$\tilde{H} = \frac{H}{\left[1 + \frac{r^2}{H^2}\left(\frac{1 - \frac{\Omega^2}{\Omega_K^2} - \frac{v_r^2}{r^2\Omega_K^2}}{1 - v_r^2/c_s^2}\right)^2\right]^{1/2}} \tag{10}$$

This prescription leads to a viscosity which decreases with increasing v_r, and drops by several orders of magnitude in the region close to the stellar surface where the pressure gradient is high and the radial scale height is smaller than the vertical one. Some models with large values of α still have a tendency to develop very high radial velocities. We found out that for $\alpha \gtrsim 0.2$ the radial infall velocity reaches supersonic values. For $\alpha \approx 0.1$, the radial velocity might take supersonic values, but as it approaches stcacly-state it becomes subsonic.

For stability reasons, we choose in some models $\nu_r = 3\nu$. This ensures that the models reache smoothly the steady state, while local oscillations (of M) decay more quickly. This condition is then replace by $\nu_r = \nu$, as the models approach steady state.

2.2.5. *The opacity law*

The opacity is an important ingredient in the modeling of accretion discs. An abrupt jump in the opacity occurs around $T \approx 10^4$ (due to the transition from ionized to neutral Hydrogen) and changes drastically the nature of disc: it gives rise to thermal instability responsible for the outbursts seen in FU Orionis stars. In these systems the "jump" appears in the ionization front located at several stellar radii (Bell et al. 1995), In cooler discs (with smaller mass accretion rates), one expects the ionization front to be located at smaller radii, not very far from the stellar surface and the hotter BL. It is, therefore, important to include the exact opacity law in models of accretion disc BL around YSOS and especially around the "cooler" T Tauri stars. In previous works (steady--state calculations of Popham et al. 1993 and Lioure & Le Contel 1994) the opacity gap was not included in the opacity law.

111 this work the analytical form of the opacity used was first developed by Lin and Papaloizou (1985), and then implemented (in the range $T < 3000K$) by Bell and Lin (1994). The opacity (frequency averaged) is written

$$\kappa = \kappa_i \rho^{a_i} T^{b_i}, \tag{11}$$

where $i = 1,..8$ accounts for eight different regimes of temperatures and densities (see Dell and Lin 1994 for more details). The opacity "gap" occurs around $T = 104K$ for practically all densities.

2.3. The numerical method

The numerical method used in this work is a time-dependent Chebyshev spectral method developed to treat astrophysical flows (Godon & Shaviv 1993). This method has been implemented recently to treat accretion disc boundary layers, and details can be found in Godon et al. (1 *995).* The spatial dependence of the equations is treated with the use of a Chebyshev method of collocation], while the temporal scheme of the equations has now been further improved with the usc of an explicit fourth order Runge-Kutta method. The method makes usc of Fast Fourier Transforms and spectral filters. The boundary conditions (section 2.2.3) are imposed directly on the characteristics of the flow at the boundary, ensuring therefore that no oscillations (or instabilities) emanate from the boundary. Implementations of the code, in the in-escnt work, in cl udc the fourth-order Runge-Kutta temporal scheme, and the usc of a new differentiation operator. The new differentiation operator (Kosloff & Tal-Ezer, 1993) allows one to chose the grid points (collocation points) more arbitrarily. This enable one to resolve sharp transition regions (like the ionization front in the disc) more efficiently.

3. Results and Discussion

in the present calculations, wc have chosen an accreting pre-main sequence star with a radius $R_* = 2.15]/0$ and a mass $M_* = 0.8\,M_\odot$. The outer envelop of the accreting star is assumed to rotate at a rate $\Omega_* = 0.1\ \Omega_K (r = R_*)$. Some other models have been calculated with $R_* = 1.6, 4.3 R_\odot$ and $M_* = 1\ M_\odot$. The accretion mass rate was taken in the range $\dot{M} = 5$ x 10^{-9} -- $10^{-7}\,M_\odot/y$. Different values of the viscosity parameter α were tested on the models. The main results arc listed in "1'able 1. Not all the models computed arc presented in this work. The important input parameters arc the mass of the accreting star (column 2), its radius (col.3), the angular velocity at the stellar surface (4), the mass accretion rate (5) and the alpha viscosity parameter (6). The important output parameters arc the vertical thickness of the accretion disc in the inner region of the disc (7), the width of the thermal boundary layer (the region overwhich the temperature in the inner disc is significantly higher than the disc temperature, col.8), the width of the dynamical boundary layer (region overwhich the angular velocity in the inner disc departs from its Keplerian value, col.9), the maximum effective temperature in the thermal boundary layer (1 O), the optical depth in the boundary layer (1 2), the fraction of ionized Hydrogen in the boundary layer ($H^+_{BL} = 1$ for fully ionized and $H^+_{BL} = 0$ for a neutral gas, co]. 13), the optical depth in the disc (col. 14) and the fraction of ionized gas in the disc (co]. 15). In all the models, the mid-plane temperature (T_c) in the boundary layer region is of a few $10^4\,K$ and the matter is almost completely ionized. The maximum effective temperature in the boundary layer is in the range $T \approx 5 - 6$ x $10^3 K$.

For low values of the viscosity parameter ($\alpha \leq 0.05$), the disc (directly adjacent to the outer edge of the thermal boundary layer) is completely neutral with a mid-plane temperature of the order of a few $\times$ 1 $0^3 K$. In figure 1 we snow the mid-plane temperature T_c for the first model of 'J'able 1. The thermal boundary layer extends to about $0.2 R_*$, where a very sharp transition occurs. At larger radii the temperature drops by an order of magnitude. The density in the boundary layer region (Figure ‘2) is lower by one order of magnitude than in the inner region of the disc directly adjacent to it. This is easily explained since the pressure through the ionization transition region dots not vary very much. A look at the angular velocity shows that the model in this region is still rotating at a Keplerian velocity (Figure 3). There is clearly two regions: the thermal boundary layer completely ionized and the disc completely neutral. In figure 4 wc show the vertical thickness H/r in the inner part of the disc. In the present calculation, the ionization transition is located about at the same place for all models, and dots not move with time. It cannot therefore be considered as an ‘ion ization front’ but rat hcr as an ionization transition. The opacity in the disc is very small and the disc is optically thin ($\tau << 1$). However, since the slope of the opacity $(\partial\kappa/\partial T)$ is positive, the disc has eventually slightly increased its temperature to cool efficiently. The optical depth in the boundary layer region is $\tau \approx 30$ and increases with decreasing α. This is justified by the fact that at a given accretion mass rate, the relation M $\approx v_r\rho \approx \alpha\rho$ holds. Consequently, on expects the density and the optical depth to decrease (increase) with increasing (decreasing) α.

For higher values of the viscosity parameter $\alpha \approx 0.1$, the optical depth in the boundary layer decreases almost to one, the boundary layer stays almost con ipletel y ionized. However, the inner part of the disc, adjacent to the outer edge of the thermal boundary layer, is slightly heated by diffusion of energy from the boundary layer region, which is now somewhat hotter than in the case $\alpha \approx 0.01$ (the boundary layer with a smaller optical depth cools less efficiently). This region of the disc has now a mid-plane temperature around $10^4 K$, and is therefore unstable. The Hydrogen is partially ionized. During the computation, which are time dependent, this region of the disc occasionally jumps temporarily into a neutral phase. All the time dependent calculations relax toward steady-state through local oscillations of $\dot{M}$. These oscillations are not associated with the viscous instability of the disc, since the instability is not expected to appear in the inner part of the disc for $\alpha \approx 0.1$ (Papaloizou & Stanley 1986). These oscillations are just the relaxation of the model from the initial condition to tile steady state. When the gas is partially ionized and unstable, these small amplitude oscillations can cause it to ju rnp temporarily into a completely neutral or ionized phase.

Models with $\alpha \geq 0.2$ all exhibit supersonic radial infall velocities. Therefore, wc compute only models for lower values of alpha, in agreement with the viscosity prescription developed from a causality formalism by Nai ayan, Loeb & Kumar (1994).

All the models in this work exhibit a boundary layer temperature rather low, consistent with the results of Regev & Bertout (1995), who also do not use a flux boundary condition at the inner boundary (they use a temperature boundary condition, while in the present work we use a non-flux condition). Simple estimates of optically thin boundary layers ($\tau \approx 1$) predicted temperature in the range 7,000 – $11,000K$ (Basri & Bertout 1989; Hartigan et al. 1991), assuming $\alpha = 1$. However, the temperature of these models appears to depend on the value of the alpha viscosity parameter. in the work of Basri & Bertout (1989) two models of DN Tau were calculated. A first model with $\alpha = 1$ led to a BL temperature of $\approx 11,000K$, while the other model of DN Tau, with $\alpha = 0.1$, led to $T \approx 7,000K$. Basri & Bertout (1989) claimed that the resulting spectra of the models did not show a strong dependence on the boundary layer temperature. Another agreement with the models of Basri & Bertout is the increasing boundary layer temperature with decreasing mass accretion rate (when $\dot{M} < 10^{-7} M_\odot/y$). This increase in the temperature is consistent with the optically thin models ($\tau \approx 1$), where the low accretion models have lower densities, and therefore a smaller optical depth. These models cool less efficiently than models with higher accretion rates and densities, which have a larger optical depth.

In this work, we have shown that the boundary layer of T Tauri stars can have an optical depth of the order of one at low mass accretion rates, when the alpha viscosity parameter is large enough.

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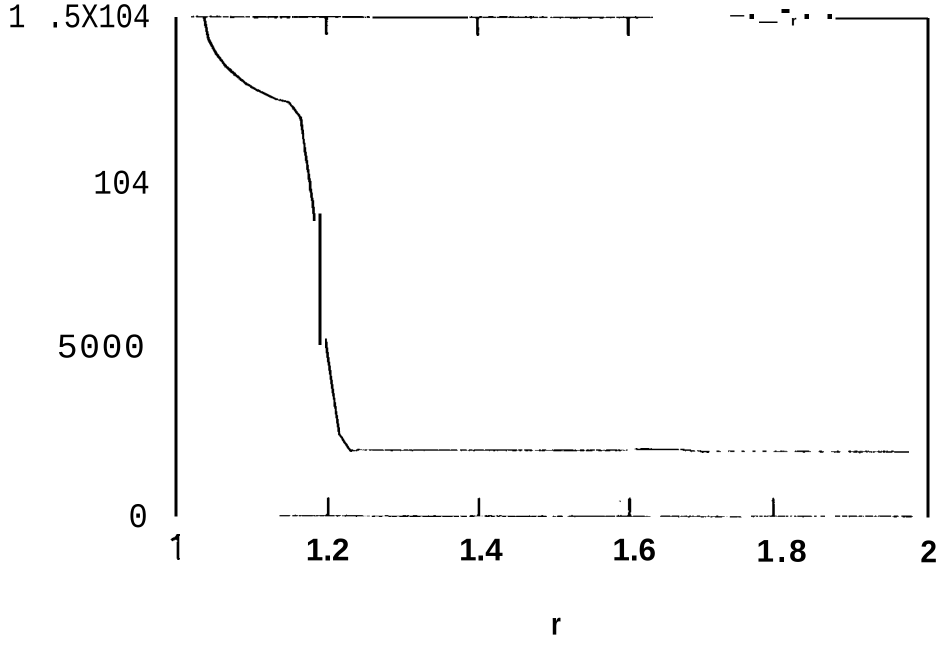
Fig. 1.- The mid plane temperature T_c is shown for the first model of 'Table 1. The temperature is in Kelvin and the radius is in units of R_*. In the inner ($r < 1.2\,R_*$) thermal boundary layer the temperature is above 10^4 K and the matter is completely ionized. In region of the disc directly adjacent to the thermal boundary layer ($r > 1.2R_*$) the temperature is of $\approx 2000K$ and the matter there is completely neutral.

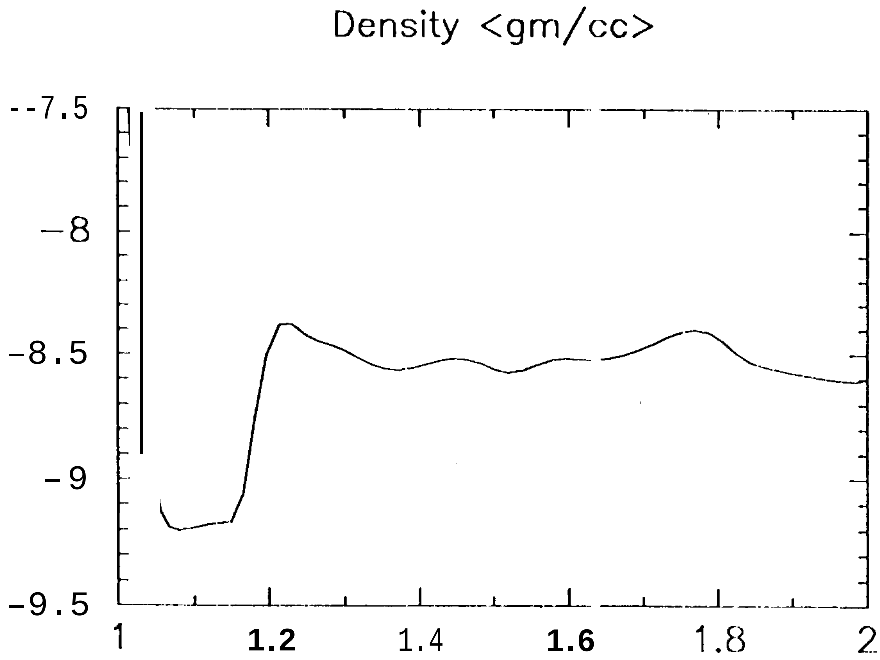
Fig. 2---- The density p of the first model (in Table 1) is shown in a log scale. The units of density arc *gin/cc* and the radius is in units of R_*. in the inner thermal boundary layer region ($r < 1.2R_*$) the density is significantly lower than in the outer neutral disc ($r > 1.2R_*$). In the disc the density is not smooth since local oscillations (due to the relaxation of the model) of $\dot{M}$ arc still present (see also text).

Fig. 3.- The angular velocity $\Omega(r)$ of the first mode] of Table 1 is shown as a function of the radius r/R_*. The velocity is in units of $\Omega_K(r =$ R. (the Keplerian angular velocity at one stellar radius). The dynamical boundary layer is only a few percent of the radius ($\approx$ 0.05- 0.06).

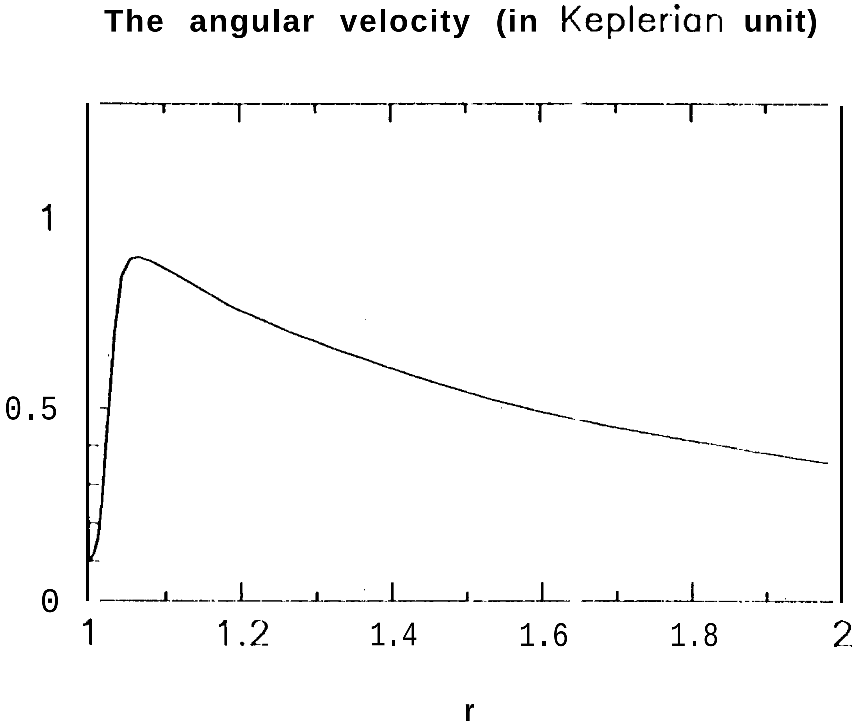
Fig. 4,- The vertical thickness of the disc H/r is shown for the first model of '1'able 1. In the thermal boundary layer the vertical thickness is roughly 3 times larger than in the region of the disc directly adjacent to it.

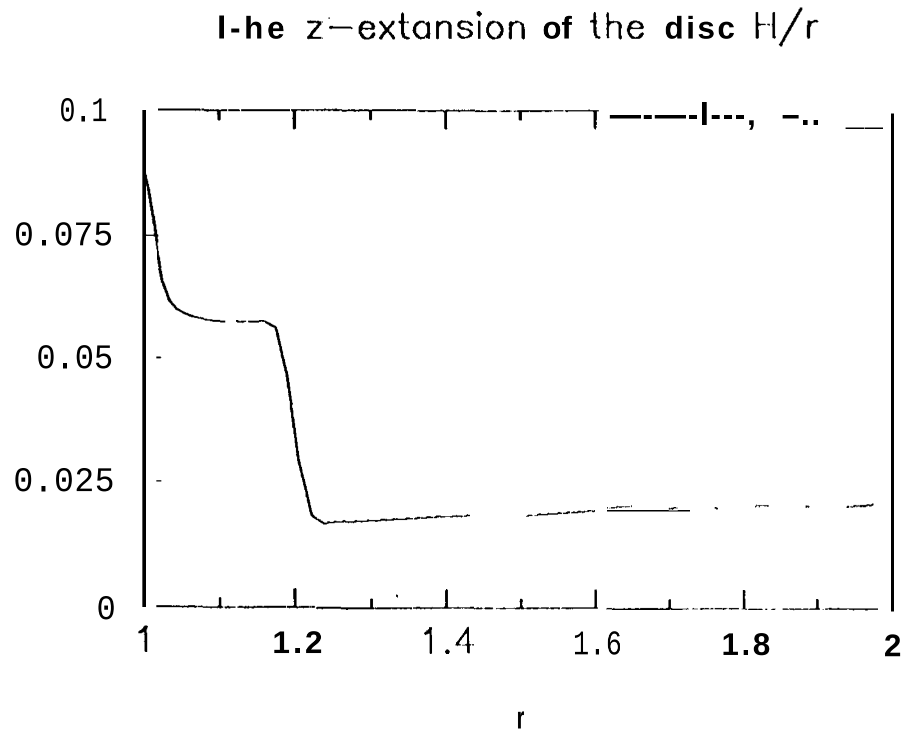
The mid---plane temperature <Kelvin>





r


The angular velocity (in Keplerian unit)
1
0.5
0
1
1.2
1.4
1.6
1.8
2
r



I-he z-extansion of the disc H/r
0.1
0.075
0.05
0.025
0
1
1.2
1.4
1.6
1.8
2
r

TABLE 1

BOUNDARY LAYER MODELS FOR CLASSICAL T TAURI STARS

[1] star	[2] M_* $(M_\odot)$	[3] R_* $(R_\odot)$	[4] Ω_* (Ω_{*K})	[5] $\dot{M}$ $(M_\odot/y)$	[6] α	[7][a] H (r)	[8] δ^{Th}_{BL} (r)	[9] δ^{dyn}_{BL} (r)	[10] T^{Max}_{eff} (10^3K)	[11] BC	[12] τ_{BL}	[13] H^+_{BL}	[14] τ_D	[15] H^+_D
T Tau	0.8	2.15	0.1	5.0×10^{-9}	0.05	0.06-0.02	0.20	0.04	6.4	I	30	1.	<<1	0.
	0.8	2.15	0.1	1.0×10^{-8}	0.01	0.06-0.01	0.20	0.04	6.1	I	$\gg 1$	1.	<<1	0.
	0.8	2.15	0.1	3.0×10^{-8}	0.03	0.06-0.02	0.20	0.05	5.7	I	35	1.	<<1	0.
	0.8	2.15	0.1	3.0×10^{-8}	0.10	0.06-0.07	0.10	0.03	6.1	I	5-20	1.	20	.95
	0.8	2.15	0.1	6.0×10^{-8}	0.20	[b]0.06-0.07	0.10	0.03	6.0	I	2-10	1.	20	.95
	0.8	2.15	0.1	5.0×10^{-7}	0.16	0.05-0.07	0.15	0.04	6.0	I	30	1.	$\gg 1$	.90
	1.0	1.6	0.1	1.0×10^{-8}	0.05	0.04-0.02	0.15	0.04	5.7	I	4-10	1.	<<1	0.
	1.0	4.3	0.1	5.0×10^{-7}	0.05	0.07-0.03	0.15	0.05	4.2	I	20	1.	<<1	0.

NOTE.-[12] & [14]: the optical depth in the boundary layer region and in the region of the disc adjacent to it; [13] & [15]: the fraction of ionized Hydrogen in the BL region and in the disc,

[a] In column 7, the first value corresponds to H/r in the boundary layer region, the second value refers to the region of the disc. In most of the models H in the boundary layer region is larger than in the inner part of the disc, in some models, however, H increases monotonously out ward

[b] This high value of α leads to a supersonic radial infall velocity.